Draft Lake Ozette Sockeye Limiting Factors Analysis

April 24, 2008
Version 9_9

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DISCLAIMER:
April 2008 Draft of the Lake Ozette Sockeye Limiting Factors Analysis (LFA).

The LFA describes and evaluates limiting factors affecting the survival and productivity of Lake Ozette sockeye salmon. Current habitat conditions and limiting factors in the Ozette River, the lake, and tributaries are a function of the cumulative effects of all past activities. Where the LFA describes habitat impacts from forestry-related activities, this description refers to past activities and not to future activities conducted under the Washington State Forest Practices Habitat Conservation Plan (FPHCP). The effects of implementation of the FPHCP on sockeye habitat and population levels can only be determined from an intensive future monitoring program. It is the goal of the LFA to provide guidance as to where and how this monitoring could be most informative.

Many hypotheses presented within the Ozette LFA are supported by substantial data. Others require additional investigation. A scientific hypothesis must be reasonable, have a definable null hypothesis, and be testable. It is not necessary, nor is it possible, to have sufficient data to confirm or refute the hypothesis at the time that it is formulated.

The authors are committed to the recovery of Lake Ozette sockeye, and we believe that this is possible only with a thorough and accurate understanding of all of the factors limiting sockeye productivity and their interrelationships. The LFA establishes a reasonable set of hypotheses based upon available information and promotes the concept of future research aimed at testing these hypotheses. We firmly believe that this approach is consistent with the best available science, and, at the same time, we welcome and will carefully consider all substantive comments.

PREFERED CITATION:

Haggerty, M.J., Ritchie, A.C., Shellberg, J.G., Crewson, M.J., and Jalonen, J. 2008. Draft Lake Ozette Sockeye Limiting Factors Analysis: Version 9_9. Prepared for the Makah Indian Tribe and NOAA Fisheries in Cooperation with the Lake Ozette Sockeye Steering Committee, Port Angeles, WA. Available at: http://www.mhaggertyconsulting.com/Lake_Ozette_Sockeye.php

EXECUTIVE SUMMARY

PURPOSE

This report summarizes previously available information relating to factors limiting the survival and productivity of Lake Ozette sockeye salmon (*Oncorhynchus nerka*), presents and summarizes new information and data, and comprehensively analyzes factors potentially limiting sockeye salmon productivity and recovery. Lake Ozette sockeye salmon were listed as threatened under the Endangered Species Act (ESA) in 1999. This report represents an important step in identifying factors that need to be addressed to rebuild the sockeye salmon population to a healthy level, helping to fulfill a local management goal that has stood for many decades. In addition, the report provides critical information on factors limiting sockeye productivity and viability that the National Marine Fisheries Service (NMFS) has used to complete a recovery plan for the Lake Ozette sockeye, as required by the ESA.

BACKGROUND

Historically, Lake Ozette, the Ozette River, and tributaries draining into the lake were important sources of salmon available for harvest in regional fisheries by the Makah Indian Tribe (Swindell 1941; Gustafson et al. 1997) and European settlers in the area. Within the greater Lake Ozette ecosystem and Olympic National Park (ONP), Lake Ozette sockeye salmon are a critical component of biological integrity, linking freshwater, marine, and terrestrial ecosystems.

The decline in harvest of Lake Ozette sockeye salmon from a high of more than 17,500 fish in 1949 (Washington Department of Fisheries 1955) to a low of 0 in 1974 and 1975 (Jacobs et al. 1996) catalyzed research into the limiting factors affecting Lake Ozette sockeye salmon. In 1976, the Makah Tribe requested assistance from the U.S. Geological Survey (USGS) to determine the preferred and observed freshwater habitat conditions of Lake Ozette sockeye, and assistance from the U.S. Fish and Wildlife Service (USFWS) to determine the sockeye's habitat status and limiting factors. These requests resulted in studies by Bortleson and Dion (1979) and Dlugokenski et al. (1981), studies that provided a tremendous amount of baseline data but did little to determine the primary factors affecting the decline and/or recovery of the sockeye population.

In 1981, the first meeting of the Lake Ozette Sockeye Steering Committee was convened. Initial participants included the Makah Tribe, ONP, USFWS, Washington Department of Fisheries, the University of Washington, and Crown-Zellerbach Corporation. The initial focus was on hatchery supplementation as a potential means to quickly bolster sockeye abundance from depressed levels. The committee met over the next two years and helped to establish the Umbrella Creek hatchery. However, multi-agency recovery efforts waned. Between 1983 and 1993, few meetings were held and only a few independent studies were conducted on Lake Ozette sockeye salmon (Blum 1988; Beauchamp and LaRiviere 1993). In 1994, ONP funded a study to compile existing data on Lake Ozette sockeye and assemble a panel of experts to make recommendations on monitoring and management. Despite being the most comprehensive document of the time, the resulting report by Jacobs et al. (1996) was unable to specifically define the population limiting factors and concluded that the population decline was likely the result of a series of cumulative impacts including (in no order of priority): 1) introduced species, 2) predation, 3) loss of tributary spawning populations, 4) decline in the quality of beach spawning habitat, 5) short-term unfavorable ocean conditions, 6) historical over-fishing, 7) introduced disease, and 8) a combination of factors.

In 1999, the NMFS listed Lake Ozette sockeye salmon as threatened under the Endangered Species Act (64 FR 14528; 70 FR 37160). Lake Ozette Chinook (*Oncorhynchus tshawytscha*) and chum (*Oncorhynchus keta*) salmon populations are not currently ESA-listed, but both populations are nearly extinct or functionally extinct. Bull trout (*Salvelinus confluentus*) are historically absent from the Lake Ozette watershed. Largely as a result of the 1999 ESA listing, multi-agency efforts to coordinate research and recovery planning resumed, and the Lake Ozette Sockeye Steering Committee was reorganized and expanded to include NMFS, as well as local landowners and other interested parties. The Lake Ozette Steering Committee initiated the development of a Hatchery and Genetic Management Plan (HGMP)/Joint Resource Management Plan (JRMP) for Lake Ozette Sockeye Salmon (Makah Fisheries Management 2000). Work also began on the Limiting Factors Analysis (LFA) report in 1999. NMFS approved the HGMP in 2004.

The HGMP and draft LFA have been used as guides for interim research and monitoring until the Final LFA and the NMFS Lake Ozette Sockeye Salmon Recovery Plan could be completed. The Makah Tribe, Olympic National Park, and co-managers have recently implemented over a dozen detailed field investigations designed to increase understanding of the spatial distribution of anadromous fish and the habitat limiting factors in Lake Ozette and its tributaries. Additional funding made it possible to complete the LFA report in late 2004.

ORGANIZATION OF LIMITING FACTORS ANALYSIS

Within the context of this report, limiting factors are defined as physical, biological, or chemical conditions (e.g., inadequate spawning habitat, insufficient prey resources, or deleterious suspended sediment concentrations) experienced by sockeye at the spawning aggregation scale that result in a reduction in viable salmonid population (VSP) parameters (abundance, productivity, spatial structure, and diversity). Key limiting factors are those with the greatest adverse impacts on a population's ability to reach its desired status. Factors responsible for the decline of the population (factors for decline) may or may not be current limiting factors, since certain activities that may have contributed to decline may no longer be operating (e.g. commercial sockeye harvest). This report is not intended to be a review of previous factors for decline, but instead represents a thorough investigation of factors currently limiting VSP parameters.

The report is divided into seven main sections:

- Introduction (Chapter 1)
- Fish Populations of the Lake Ozette Watershed (Chapter 2)
- The Sockeye Salmon Population (Chapter 3)
- Habitat Conditions Affecting Lake Ozette Sockeye (Chapter 4)
- Limiting Factors Affecting Lake Ozette Sockeye (Chapter 5)
- Analysis of Limiting Factors (Chapter 6)
- Research, Monitoring, and Evaluation Needs (Chapter 7)

Limiting factors affecting sockeye salmon are discussed by geographical area and life history stage. Factors are rated for degree of impact and presented as a series of hypotheses and sub-hypotheses. These hypotheses are intended to serve as the scientific foundation for identifying recovery actions in the Lake Ozette sockeye recovery plan.

WATERSHED SETTING

The Lake Ozette watershed (88.4mi^2) is located along the coastal plain of the northwest tip of the Olympic Peninsula in Washington State. Lake Ozette is a monomictic and oligotrophic-to-mesotrophic lake, which drains to the Pacific Ocean through the very low gradient, sinuous, 5.3-mile-long Ozette River. Lake Ozette is the third largest (7,550 acres) natural lake in Washington State. It has average and maximum depths of 130 feet and 320 feet, respectively, and the observed water surface elevation fluctuates from 30.8 to 41.5 feet above mean sea level. The tributary drainage basin area is 77 mi^2, drained by several large tributaries and numerous smaller tributaries.

Lake Ozette watershed geology is a mix of gently sloping glacial deposits, hilly sedimentary rock, and steep volcanic flows and breccias. The temperate coastal-marine climate is characterized by cool summers, mild wet winters, and an average annual precipitation of 102.6 inches. The watershed is predominantly forested by coastal temperate rain forest conifer and hardwood species. Tributary streamflow is highly variable, similar to other perennial rain-dominated streams in the region with little snow storage.

Land use in the watershed has ranged from traditional Native American management of old-growth forest, to European settler homesteading along the lake and stream valleys, to commercial timber production and National Park management. Currently, land ownership in the watershed is 73% private land, 15% Olympic National Park, 11% Washington State, and 1% Tribal. Private timber companies own approximately 93% of the four largest tributaries to Lake Ozette. Timber harvest levels accelerated over the period of record, with 8.7% of the watershed area clear-cut by 1953, increasing to 83.6% of the watershed area clear-cut by 2003. Natural disturbance in the watershed was dominated by wind and hydrogeomorphic events, while contemporary disturbance additionally includes timber harvest, road construction and maintenance, residential and agricultural development, channelization and direct and indirect stream wood clearance.

FISH POPULATIONS IN THE LAKE OZETTE WATERSHED

The Lake Ozette fish community includes a rich array of approximately 25 species of fishes. There are seven species of salmonids present in the lake system and 18 non-salmonid fish species, of which five are exotic. In addition to sockeye, these other species are important indicators of ecosystem health, and thus this report includes summary information and data for many of them. For species that are potential competitors with or predators of sockeye salmon, additional information on habitat utilization, diets, and relationships to sockeye salmon are included. Of these species, the most important competitors are kokanee salmon (non-anadromous *Oncorhynchus nerka*) and threespine stickleback (*Gasterosteus aculeatus*), while the most important predators are coho salmon juveniles (*O. kisutch*), cutthroat trout (*O. clarki*), sculpin (*Cottus Spp*), northern pike minnow (*Ptychocheilus oregonensis*) and largemouth bass (*Micropterus salmoides*). While few data are available regarding non-salmonid population integrity, data on other salmonid populations inhabiting the basin over the past century indicate either generally decreasing population trends over time (*O. tshawytscha; O. keta; O. kisutch*) similar to sockeye, or static or unknown trends (non-anadromous *O. nerka, O. mykiss*). Coho salmon have shown small but significant population increases during recent years but are still well below historical abundance levels.

SOCKEYE SALMON POPULATION LIFE HISTORY AND STATUS

Ozette sockeye life histories are described and evaluated assuming a single population divided into seven life history phases:

1. Adult sockeye entering the system (April-July)
2. Adult holding in the lake (April-January)
3. Spawning (October-January) and incubation (October-March)
4. Fry emergence and dispersal (March-April)
5. Juvenile freshwater rearing (Multi-year)
6. Seaward migration (March-June)
7. Marine/ocean phase (Multi-year)

Two spawning groups (i.e., beach-spawning and tributary-spawning) are discussed independently during their spawning, incubation, emergence and dispersal phases. Sockeye immigration into and through the Ozette River typically peaks in early June, with short residence times in the river (average transit time equal to ~65 hours). Nighttime migration predominates during low lake/river levels, while higher lake/river levels result in increased daylight migration. Extensive lake holding occurs below the thermocline at minimum depths ranging from 30 to 100 ft for about six months, until the lake turns over and de-stratifies at the onset of the wet season.

The timing of sockeye salmon adult entrance and holding in tributaries is largely controlled by streamflow increases during the onset of the wet season (generally in October). A majority of tributary spawners use Umbrella Creek, with additional fish spawning in Big River and Crooked Creek. Fish typically spawn in late November in gravel riffles and glides and less commonly in pools, alcoves, and side channels. Average female fecundity is 3,050 eggs with fish size ranging from 430 to 690 mm, which is similar to beach spawning sockeye. Tributary incubation temperatures typically range from 3-8°C, with fry emergence occurring 100-130 days after fertilization.

There are two known active beach spawning sites along the shores of Lake Ozette: Allen's Beach and Olsen's Beach. Historically, the beach just north of the confluence with Umbrella Creek (i.e., Umbrella Beach) was also used for spawning. Other locations around the lake are hypothesized to have provided spawning habitat. Beach staging begins in mid- to late October, with spawning beginning as early as November and ending in late January or early February. Habitat usage varies considerably between and within the two beaches, with core, concentrated, and dispersed spawning sites. At Olsen's Beach, competition is intense for the small core spawning area where upwelling groundwater occurs through small gravel and sand. Concentrated sites surround the core site in substrate lacking upwelling and ranging from cobble/large gravel to coarse sand and silt. Substrate and spawning sites are often surrounded by or found within large patches of submerged shrub vegetation. Dispersed sites are scattered along long stretches of beach, and are at a remove from core and concentrated spawning areas. Beach slopes used for sockeye salmon spawning range from 2% to 15%. Spawning is concentrated in the middle elevation beach in 2 to 6 ft of water, with redds observed at depths up to 20 ft in concentrated sites. Spawning along Allen's Beach is significantly more dispersed than on Olsen's Beach, with at least one area of concentrated spawning. Substrate varies from silt and sand at the south beach to gravel and cobble-gravel mix in the north. Spawning depths range from 1 to 33 ft, with several spawning sites associated with seeps and springs. Incubation temperatures are warmer on the beaches than the tributaries (6-10°C), especially in groundwater upwelling sites, resulting in shortened incubation periods to time of fry swim up (~100 days).

Beach fry dispersal after emergence is assumed to consist of a rapid migration to the limnetic zone; however, additional data are needed on sockeye fry behavior during this life phase. Downstream tributary fry dispersal and movement after emergence corresponds with streamflow and appears to occur predominantly at night soon after emergence. Immediate limnetic rearing is assumed, but littoral data are lacking. In offshore rearing areas sockeye salmon mix with kokanee salmon, and the two *O. nerka* races become morphologically indistinguishable.

The year-round primary prey of juvenile sockeye/kokanee salmon is *Daphnia pulicaria*, with additional consumption of benthic invertebrates, adult insects, and copepods. Juvenile sockeye and all year classes of kokanee consume less than 1% of the monthly standing stock of *Daphnia pulicaria* > 1.0 mm in size, suggesting that food available for rearing fish is not limiting *O. nerka* productivity.

At the onset of their spring-time seaward migration, sockeye smolts migrate along the nearshore lake environment and emigrate down the Ozette River predominantly at night. More than 99% of the juvenile sockeye salmon emigrating from the lake to ocean are age 1+, indicating that few juvenile sockeye rear in the lake for more than one summer. Lake

Ozette sockeye salmon smolts are large, averaging between 11.3 to 13.0 cm fork length, making them the third largest yearling sockeye smolts in the world. Little is known about the behavior of Lake Ozette sockeye immediately after smolt emigration to sea. The Lake Ozette system does not include a sizeable estuary, but the nearshore region surrounding the mouth of the Ozette River is an extensive, complex, and shallow sub-tidal environment, with high apparent productivity for sockeye salmon, despite the presence of many marine piscine predators. Few data are available regarding Lake Ozette sockeye salmon ocean distribution, and their distribution and behavior during this life history phase must be extrapolated from studies of other sockeye salmon populations.

Generally, juvenile sockeye are present close to shore from Cape Flattery to Yakutat in July and August, and scarce to absent in areas farther offshore. Juvenile sockeye remain primarily inshore through October, before moving offshore in late autumn or winter. In Bristol Bay where inner coastal waters are less productive than offshore waters, juvenile sockeye migrate to the outer Bay within 2 to 6 weeks. They remain in the outer bay for an undetermined length of time, staying near the coast during migration. Average marine survival rates for Lake Ozette sockeye are thought to be relatively high (15-17%). The vast majority of Lake Ozette sockeye spend 2 to 2.25 years at sea before returning to the lake, but some return after only one year, and others remain at sea for as many as three years.

Out-of-basin origin hatchery sockeye were released into Lake Ozette episodically between 1936 and 1983 through transplants derived from Baker Lake and Lake Quinault broodstocks. All subsequent hatchery stocking efforts have relied on within-basin broodstock sources. Based partially on recommendations of Dlugokenski et al. (1981), the Umbrella Creek Hatchery was established in 1983 as a tool to reintroduce and rebuild sockeye populations in the Ozette tributaries. Broodstock were collected from Olsen's Beach almost every year between 1983 and 1999. Spawners collected from Allen's Beach were also occasionally used as broodstock during this span. On average, 100 adults were collected for spawning each year. Eyed eggs and fry grown from these egg sources were released into Lake Ozette and major tributaries to the lake during this time.

After the ESA listing of sockeye in 1999, the Makah Tribe and WDFW worked with NMFS to assemble a Hatchery and Genetic Management Plan that would adequately protect the listed population and would be used to guide all hatchery-based sockeye salmon restoration actions. The HGMP stipulated that, beginning in 2000, the collection of broodstock from spawning beaches for hatchery production would cease, and broodstock for the supplementation program would be collected from adult sockeye salmon returns to Umbrella Creek. Juvenile fish were only to be released into Umbrella Creek and Big River.

However, implementation of the HGMP alone will not result in recovery of Lake Ozette sockeye salmon. The HGMP is part of the overall comprehensive recovery plan/process that integrates hatchery supplementation and reintroduction efforts with habitat protection, assessment, and restoration so that hatchery and habitat components can work in concert to promote sockeye recovery. NMFS (2004) concluded that the hatchery program was not likely to increase the spatial structure of the beach spawning aggregations within Lake Ozette, but that the tributary-based hatchery program was likely to increase the spatial structure of the ESU as a whole and increase life history diversity and the resiliency of the population. Determinations of whether and how to supplement or reintroduce lake spawning aggregations will be made after further research in this area.

The Lake Ozette sockeye salmon ESU is believed to have been historically composed of a single population with substantial sub-structuring of individuals into multiple spawning aggregations (BRT 2003). Gustafson et al. (1997) described the Lake Ozette sockeye salmon population as genetically distinct from all other sockeye salmon stocks in the Northwest. Hawkins (2004) found that there was very little genetic difference among the sockeye spawning aggregations at Olsen's Beach, Allen's Beach, and Umbrella Creek. However, the author found significant genetic differences between cohort lineages along the predominant 4-year brood cycle and found that those lineages were most closely related among common brood years, independent of sampling locations. Hawkins (2004) described the Lake Ozette kokanee population structure as likely one panmictic group, having found no genetic differences among the sample collections (between locations or brood years) within the study. Sockeye and kokanee-sized *O. nerka* are known to interact during the spawning phase on both beaches and in the tributaries; however, visual observations may confuse kokanee and residual, jack, or hybrid sockeye salmon. Hawkins (2004) indicated that hybridization between sockeye and kokanee is persistent but of low enough frequency to maintain the large genetic differences observed between these two *O. nerka* races.

Only marginal data are available for estimating historical escapement levels for Lake Ozette sockeye. Partial weir counts, lacking any harvest data, exist for the period from 1924 to 1926, making it impossible to estimate total run size for this period (Kemmerich 1945). Between 1948 and 1976, harvest data were collected (WDF 1955), but no escapement data were collected for the same period, creating substantial uncertainty regarding run sizes during this period. Blum (1988) speculated that the Lake Ozette sockeye run size exceeded 50,000 fish prior to the 1940s. Over a 20-year period, Lake Ozette sockeye harvests went from several thousand per year to zero, with insignificant (<100) to no fish harvested annually between 1973 to present.

Contemporary (1977 to present) run size estimating methods as fish enter the lake from the Ozette River have varied significantly from nighttime weir counts (1977-1981); 24-hour counts with a river-spanning picket weir with live trap attached (1982, 1984, 1986); visual nighttime counts and daytime/weekend closures using a river-spanning picket weir (1988-1992; 1994-1997); 24-hour counts with a river-spanning picket weir with an underwater video camera and time-lapse VCR and backup visual observations (1998-2001); and 24-hour counts with a river-spanning picket weir with an underwater video camera, time-lapse VCR, and backup computer hard drive digital images (2002-present). Substantial differences in older methods limited the quality of data collected and therefore likely underestimated run sizes.

Total annual lake entry run-size estimates from 1977 to present have ranged from 385 to 5,075 adult sockeye. The annual run size, considered over three periods reflecting differing census methods, has averaged 1,132 fish for 1977-1995, 2,590 fish for 1996-1999, and 4,600 fish for 2000-2003. While these run-size estimates represent the best available data, they should be used with extreme caution since the quality of estimates for many early years is poor at best (see Section 3.4). Independent estimates of the minimum number of fish spawning on Ozette beaches has increased from a low of six spawning sockeye after extensive surveys in 1989, to 32 fish in 1993, 236 fish in 1997, and 466 fish in 2002.

Much of the increase in total Ozette River run size is likely a result of increased adult returns from Umbrella Creek Hatchery releases and increased natural production in Umbrella Creek. For example, nearly 210,000 brood year (BY) 1996 fed fry and fingerlings were released into Umbrella Creek in 1997, which subsequently comprised a large portion of the brood year 2000 adult run. In addition, the estimated numbers of smolts emigrating from the lake in 2002, 2003, and 2004 from the smolt trap were dramatically higher than any past year's estimates.

Sockeye spawning ground surveys in Umbrella Creek initially recorded low numbers of fish (<50) from 1988 to 1994, with recent peak adult counts ranging from 44 to 1,709 adults from 1995 to 2004. Total run-size estimates in Umbrella Creek have recently ranged from 1,709 to 4,442 adults from 2000 through 2004, which represented 34 to 68% or more of the total estimated Lake Ozette sockeye adult run size. Estimates of adult sockeye run size for Big River and Crooked Creek are not as accurate due to less survey effort and no tag and recapture program. Pending the onset of supplementation program origin adult returns to Big River, numbers of returning fish to these tributaries have remained at low levels.

Sockeye productivity estimates are limited by the quantity and quality of the population data described above. For 1988 and 1990, Jacobs et al. (1996) estimated marine survival at 27% and 18%, spawner-recruit ratios at 0.99 and 1.89, and smolts-per-spawner ratios at 3.6 and 10.5, respectively. From recent data at Umbrella Creek, natural origin recruits per spawner estimates ranged from 0.9 to 3.3 from 2000 through 2002, averaging 1.9. Total survival from hatchery fingerling release to adult return to Umbrella Creek for return years 1999, 2000, 2002, and 2004 was estimated to be 2.03%, 1.47%, 0.81% and 0.49% respectively. Total survival from smolt to spawner for 2004 Umbrella Creek marked hatchery sockeye was estimated to be 15.5%.

HABITAT CONDITIONS AFFECTING LAKE OZETTE SOCKEYE

This report describes in detail the habitat conditions encountered by Lake Ozette sockeye salmon spawning aggregations at different life history stages in marine, estuary, and freshwater habitats. Known habitat conditions and data are described, while data gaps are highlighted.

NEARSHORE HABITAT

Nearshore physical habitat in the vicinity of the Ozette River is characterized by a gently sloping marine shore platform with abundant boulders and outcrops of resistant rock intermixed by beaches (sand to cobble) fed by bluffs and tributaries. The remote and relatively pristine condition of the shoreline in the vicinity of the Ozette River is reflected by a complex nearshore habitat that supports a wide diversity and abundance of marine life. The Ozette River estuary is small relative to nearby estuaries (<4,600 feet long by 120 feet wide), and is currently partially constricted by a gravel spit. Beyond photo evidence of significant growth of this spit over the last 50 years, little documentation of current and/or historical estuary conditions exist to allow for an assessment of effects on sockeye salmon growth and survival.

OZETTE RIVER HABITAT

The Ozette River is unique relative to other rivers on the Olympic Peninsula due to its very low gradient (0.1%) over its 5.3 mile journey, dropping only 32 feet in elevation from the outlet of Lake Ozette to the Pacific Ocean. The lake moderates the seasonal flow regime of the Ozette River dramatically, with flows ranging from less than 4 cfs to 2,000 cfs. Lake Ozette traps and prevents entrance of nearly all lake tributary sediment into the Ozette River, making bank and bed erosion, a handful of small tributaries, and Coal Creek (largest tributary) the only contemporary sources of sediment. The active river channel averages approximately 100 feet in width, with varying depths and wetted widths controlled by the water elevation of its source, Lake Ozette. The river maintains a semi-rhythmic sequence of riffles and pools, with the latter often controlled by large wood jams and the former often covered with two species of native mussels, freshwater sponges, and aquatic insects. Floodplains are relatively narrow with steep banks for much of the length. Floodplains are covered by dense conifer forest, various shrubs and wetland plants. Wetland plants include reed canary grass, an invasive plant which colonizes disturbed areas.

Besides tributaries to Ozette River, the river's entire length is now protected by either the ONP or the Makah Tribe's wilderness designation. Historically, human disturbances along the Ozette River were limited to homesteading, and later, tourist development near the lake outlet, cedar salvage along the lower river, and direct removal of instream large wood debris (LWD) along much of the river but concentrated near the lake outlet. Wood removal from Ozette River began in the late 1800s at a small scale, with most wood removed from the upper homestead area by the early 1900s. In 1952, the Washington Department of Fisheries (Kramer 1953) conducted wholesale clearing of wood from the river and removed 26 separate log concentrations. Local residents continued to clear wood from the river until the mid-1980s, when the practice was banned.

As a consequence of wood removal, pool conditions in Ozette River are impaired, with large stretches devoid of functional LWD, and with an associated loss of fish holding, rearing, and spawning habitat. The river is incapable of moving most large wood, but it will take decades to centuries for wood loads to fully recover. As a less apparent consequence, wood removal has resulted in less hydraulic roughness, reduced instream water depths, and reduced backwater effects on Lake Ozette, which has thus altered the entire hydraulic control on Lake Ozette levels and changed the in-river stage-discharge relationship. More recently, deposition of sediment originating from Coal Creek at the lake outlet has further altered lake and river levels.

Water quality conditions in Ozette River are good, except for sediment and temperature, which are affected by tributaries and the lake itself, respectively. Large amounts of fine (sand and silt) and coarse sediment are delivered to Ozette River by Coal Creek during floods, altering the local lake outlet control and substrate conditions, as well as downstream habitat conditions. Peak and 7-day average temperatures in the river regularly exceed 22 to 23°C respectively. High water temperatures observed in the Ozette River appear to be a natural condition caused by solar heating of Lake Ozette surface waters and climatic variability. Downstream cooling is minimal (less than 2°C).

LAKE OZETTE HABITAT

Lake Ozette habitat conditions are important to numerous life history stages of sockeye. Beyond providing key habitat for juvenile sockeye rearing, the lake's habitat is an integration of all cumulative upstream watershed conditions. The lake environment also controls habitat conditions downstream through the Ozette River to the ocean.

Lake productivity, and more specifically production of abundant phytoplankton and zooplankton, varies seasonally in the oligotrophic to mesotrophic lake and is a critical component of the overall sockeye smolt production because of the smolts' reliance on zooplankton. Limnological research indicates that abundant food supplies are available for juvenile sockeye salmon during their rearing period. Studies completed in the 1980s indicated that consumption demand by kokanee and juvenile sockeye rearing in the lake is satisfied by less than one percent of the instantaneous production of their preferred prey, large Daphnia (*Daphnia sp*.) throughout the growing season. In addition, Ozette sockeye smolts are the third largest (by length and weight) yearling sockeye smolts documented in the recorded literature, providing additional evidence that zooplankton populations are not limiting sockeye productivity.

The beach spawning sockeye salmon aggregations are a key component of the Ozette sockeye population. Shoreline conditions and potential sockeye spawning habitat vary greatly, both spatially and temporally, around the 36.5 mile lake perimeter, as determined by beach topography and slope, substrate size distribution, groundwater and hyporheic flow paths into beach gravel, wind fetch, fine sediment concentrations, tributary position, shoreline vegetation, riparian condition, lake level and hydroperiod, shoreline development, and other factors. The habitat review focuses on the two remaining sockeye spawning beaches (Olsen's Beach and Allen's Beach), in addition to known historical spawning locations (Baby Island and Umbrella Beach). However, it is important to note that current and recent spawning locations, as well as vegetation and substrate conditions along the lake shoreline, may not be representative of past spawning distribution and shoreline conditions. Historically, high quality spawning habitat was likely provided by numerous hydrogeomorphic situations around the lake:

- Beach spawning habitat maintained by wind- and wave-driven currents.
- Beach spawning habitat maintained by upwelling hyporheic- or ground-water in gravel or sand substrate.
- Beach spawning at or near tributary inlet deltas maintained by upwelling hyporheic flow or groundwater, and clean gravel with minimal fine sediment inputs from tributaries.

Currently, lake spawners use beach spawning habitat irrigated by wave-driven currents and/or upwelling hyporheic flows or groundwater. Seeps and springs have been mapped on both Olsen's and Allen's beaches, and appear to be areas where spawning activity is concentrated, with dispersed areas of spawning in non-upwelling areas. Zones of upwelling are warmer than non-upwelling areas during sockeye incubation and significantly cooler during summer months.

Substrate along Olsen's and Allen's beaches is a heterogeneous mixture of organic detritus, clay mud, silt, fine sand, coarse sand, pebbles, gravel, cobble, and rubble. Core spawning areas are typically located in a framework of gravel, with various levels of matrix finer sediment. Dozens of bulk gravel samples from each beach indicate that fine (<0.85mm in diameter) sediment concentrations in gravels are high, ranging from 7.0% to 72.7% of the total substrate composition. Fine sediment concentrations averaged 27.0% at Olsen's Beach, ranging from 4.6% to 44.3% in areas sampled. Allen's Beach fine sediment averaged 24.6% of total substrate composition. Fine sediment concentrations at the Umbrella Beach delta currently exceed 50%.

Due to seasonal fluctuations in lake level, vegetation (e.g., sweet gale, sedges, grass) often occupies the mid- to upper-elevations of both main spawning beaches and other lake margins. This vegetation is very effective at trapping fine sediment. Sockeye may spawn in and around this vegetation when it is submerged by high lake levels during the dormant season. Aerial photography analysis has estimated a 56% average decrease in unvegetated (bare substrate) shoreline around the lake from 1953 to 2003. At Olsen's and Allen's beaches, the decrease bare substrate shoreline was measured to be higher than average for other shoreline areas, at 66 % and 67%, respectively. Potential causal mechanisms for decreases in unvegetated shoreline include a reduction in elk shoreline grazing pressure early in the twentieth century and alterations in lake level regime and hydroperiod because of modifications in lake outlet hydraulics (e.g., Ozette River LWD removal) and lake inflow hydrology.

Riparian conditions (above typical high lake levels) around the lake are generally good to excellent, because of the retention of primary forest on the western shoreline and forest management measures providing a narrow buffer of mature trees on the eastern shoreline between the lake and adjacent clear-cuts. However, exceptions exist where the county road parallels the shoreline, where development (cabins, ranger station) has occurred, where old railroad grades exist, and where old homesteading cleared large conifer trees.

The hydrology of Lake Ozette has been poorly studied over the contemporary settlement period, but an assortment of lake level, climate, and hydrology data have been collected at various locations in the watershed and coastal region, which have been massed together to highlight major physical patterns. A stage gage at the lake outlet has been maintained semi-consistently from 1976 to 2006. Similar to regional precipitation patterns, Lake Ozette stage (which has a range of 12 ft) is typically at a maximum between December and February and at a minimum in September annually. The average peak-lake-stage timing typically lags behind average tributary-peak-discharge timing by several weeks. Annually, climatic variability has a strong effect on lake stage variability, similar to rainfall. Peak lake stages are highly correlated with total winter rainfall, while minimum lake stages are highly correlated with total summer rainfall and evaporation. During windy periods, lake stage can vary by up to 0.5 feet from north to south due to wind seiche, which is a wave oscillation lasting several hours to days following water displacement. Lake Ozette stage levels are also considerably influenced by both the hydraulic roughness conditions (e.g., LWD) in the lake outlet (Ozette River), and by vegetation and land surface disturbance condition influence on tributary inflow hydrology.

TRIBUTARY HABITAT

Lake Ozette tributary conditions are described in detail for the individual streams used directly by sockeye for spawning (Big River, Umbrella Creek, and Crooked Creek), for the streams that have a strong indirect impact on sockeye habitat (e.g., Coal Creek impacts on Ozette River and Lake Ozette) and for those tributaries that support healthy runs of kokanee (Siwash Creek). For each tributary, the floodplain, riparian, pool and LWD habitat, streambed substrate, water quality, and hydrology and streamflow conditions are described in detail. Data gaps pertaining to the status of these habitat parameters are highlighted.

Floodplain conditions for Lake Ozette tributaries vary considerably. The lower sections of most tributaries are partially disconnected from their floodplains due to incision (by approximately one meter) caused by changes in base level and lake level regime, in addition to local indirect and direct removal of LWD. Furthermore, roads located in the riparian zone have degraded floodplain conditions severely in Big River (county road and agricultural roads) and Umbrella Creek (logging roads). Road densities are less in riparian areas adjacent to Crooked and Siwash Creeks, which retain good floodplain habitat. Siwash Creek riparian habitat remains good because of remnant old growth conditions and high instream wood loads. The lower Coal Creek floodplain has been modified in contemporary times through channel incision caused by base level change (e.g., LWD removal), and by human development modifications of the confluence configuration and deltaic distributary locations.

As a consequence of its standing as the main transportation and settlement corridor in the Lake Ozette watershed, the Big River floodplain has been uniquely and significantly modified by roads, agriculture pastures, residences, channelization, LWD removal, and overall channel incision (by one to two meters). Channel incision in lower Big River has resulted partially because of base and lake level changes associated with logjam removal from the Ozette River. In addition, direct and indirect removal of LWD from Big River has contributed to incision and bed instability. Kramer (1953) describes clearing 3.5 miles of the river of logs and debris between approximately RM 2 and RM 6. Wood removal, insufficient LWD recruitment, and channel incision have reduced floodplain connectivity in Big River.

The Hoko-Ozette Road roughly follows the original wagon trail to Lake Ozette from Clallam Bay. Big River was correctly named, as for most of the year it was a small, slow-flowing stream, but during storm events, it often flooded out of its channel and occupied a large part of the floodplain valley, which encompassed parts of the trail (road), making passage on the trail (road) impossible. More recently, base level incision, road construction, channelization (rock and cars), and repeated “lifts” (which raise the level of the road to prevent flooding) have restricted channel migration, LWD recruitment, and stream-floodplain interactions. In 2003, 6.1 miles of roads were within 200 feet of the river’s bankfull edge. There is an average of 8.8 miles of road per square mile of riparian area within 200 feet of the river’s bankfull edge (range by channel segment of 6.5 to 17.8 miles per square mile), which equals or exceeds suburban or urban road densities. Rip-rap can be found along the banks of Big River in at least eight locations, preventing the river from migrating across its floodplain, and in some cases, preventing flood waters from accessing the floodplain. Several bridge crossings constrict the river and block flood flows from traveling on the floodplain (e.g., Swan Bay Road).

Agricultural development along the floodplain of Big River began in the late 19th century, when pioneer families cleared virgin forest into workable pasture. Floodplain and riparian encroachment by pastures and residences into the Big River riparian zone area (defined as the area extending 200 feet from each river bank) ranges from 0 to 15% by area. On average, 20% of the length of the river has pastures or residences within 200 feet of the bankfull edge (ranging from 0 to 36%). The lowest quality habitat segments (based on pool quality and LWD abundance) in Big River were located adjacent to pastures and/or residences.

Similar to floodplain conditions, riparian conditions along Big River are severely degraded. Nearly all (exceeding 95%) of the old growth riparian forest historically vegetating the riparian zone has been clear-cut or converted to pasture land. Extensive stands of medium-aged red alders (*Alnus rubra*) dominate the riparian forest where it remains, replacing conifers. However, some residual, large conifer trees are still present in patches, as are some continuous stream reaches of relatively young conifers. In addition, disturbed stream banks in many portions of Big River are infested with reed canary grass (*Phalaris arundinacea*). Japanese knotweed (*Polygonum cuspidatum*) and giant knotweed (*Polygonum sachalinense*) are also rapidly colonizing portions of the lower mainstem of Big River.

Riparian conditions in other Lake Ozette tributaries are also degraded. In contrast to the Big River, logging, rather than agricultural and rural development, has been the major causative factor of degradation in these other tributaries. Nearly all (exceeding 95%) of the old growth riparian forest has been harvested along most tributaries. The majority of riparian forests have been converted to stands dominated by red alder, but in scattered areas, relatively young conifers are the predominant species. Residual in-channel LWD and standing trees provide evidence of the massive trees that once existed. Small exceptions of good riparian conditions remain in portions of the Siwash and Crooked Creek watersheds, where residual in-channel LWD and intact mature riparian areas represent riparian conditions that historically existed throughout the watershed (i.e. large Sitka spruce and western red cedar).

Pool and LWD habitat quantity and quality mirror riparian conditions throughout the watershed. Beyond riparian timber harvesting, WDNR implemented stream clearing policies after 1952 and forest landowners were required to clear wood from streams when logging in adjacent riparian areas, which continued into the early 1990s as an integral part of forest practices.

Comprehensive instream pool and LWD condition data has been collected in the anadromous zone of all major tributaries. Habitat quality was rated and mapped in detail based on observations of instream wood load, large key piece frequency, and pool size and frequency. In most stream reaches with degraded riparian condition, the quantity and quality of LWD were low and below properly functioning levels, especially for the frequency of key conifer pieces (LWD greater than 50 cm in diameter). Conifer dominated the LWD piece count (69 to 83%), despite the standing of alder as the dominant species in many riparian zones. Key pieces ranged from one to four percent of the total piece count. Where present, pools formed by key-piece-sized LWD averaged nearly 1.5 to 1.8 times deeper than pools formed by medium or small LWD or free-formed pools without LWD. Recent recruitment of small and medium sized LWD appears incapable of producing the same habitat quality and complexity as those habitats formed by LWD greater than 50 cm in diameter. Pool habitat features associated with small and medium sized LWD had essentially the same attributes as free-formed pools independent of LWD. Future conifer recruitment will be minimal in many stands that are currently dominated by alder. However, the functionality of large alder recruitment in the future is unknown, as alders represented a smaller portion of past recruitment and current LWD loads. Large alder tree recruitment and LWD placement may be essential to maintain wood loads through the upcoming LWD deficit, until conifers can be planted and mature in the riparian zone.

Spawning substrate quality and quantity varies throughout the main tributaries to Lake Ozette. Past data indicate that the percent fine sediment (particles less than 0.85 mm in diameter) in spawning gravel is high in many Lake Ozette tributaries, averaging 16.1%

(wet-sieve equivalent) of the total substrate composition in Umbrella Creek, 15.7% to 17.3% in Big River, 14.0% to 23.9% in Crooked Creek, and 24.0% in Siwash Creek. Salmonid egg to alevin survival decreases when fine sediment concentrations exceed 13% (McHenry et al. 1994). In undisturbed drainage basins with geology similar to the Lake Ozette watershed, fine sediment levels rarely exceed 10% (McHenry et al. 1996). High levels of fine sediment in Lake Ozette tributaries are a partial result of naturally erosive geology. However, anthropogenic watershed disturbance, notably high road densities (5.5 to 7.5 mi/mi^2), lack of adequate road surfacing material, high road to stream connectivity, and gullying and mass-wasting associated with vegetation clearing have contributed to observed high fine sediment concentrations.

The quantity of spawning habitat available for salmon in Lake Ozette tributaries has also changed relative to historical levels. The loss of LWD in some streams has reduced the stream's ability to trap and store gravel, with bed coarsening occurring in many tributaries (e.g., Umbrella Creek). In other situations, fine sediment deposition from watershed disturbance has buried previous gravel bed reaches (e.g., lower Big River as described by Kramer 1953).

Water quality conditions in Lake Ozette tributaries vary by season and location. While winter water temperatures are within the preferred range for spawning and incubating salmonids, summer temperatures in most major tributaries regularly exceed the standard environmental temperatures preferred by salmon (10-12°C) and trout (15°C) for many weeks each summer. Water temperatures in Umbrella Creek, Big River, and Crooked Creek regularly exceed 18°C for several days to weeks each summer along lower reaches. These relatively high stream temperatures are thought to be partially a function of riparian forest disturbance and shade loss (mostly from logging during the last 50 years) and partly due to naturally elevated stream temperatures. Low dissolved oxygen conditions often accompany these higher temperatures. In addition, fecal coliform bacteria samples collected during summer months adjacent to agricultural sections of Big River have regularly exceeded Washington State Water Quality Standards (greater than 10% of samples exceed 100 colonies per 100 ml).

Turbidity measurements in Lake Ozette tributaries indicate that turbidity levels regularly exceed 100 nephelometric turbidity units (NTU) during storm events in most tributaries, with extremely high levels (greater than 500 NTU) measured in Umbrella Creek and Big River. In Coal Creek, paired measurements indicate that suspended sediment concentration (SSC) can exceed 1000 mg/L at turbidity values of 300 NTU. Peaks in turbidity and SSC closely follow the patterns of water discharge in each tributary. There is abundant sediment available in the channel network and turbidity is limited by flow-related transport capacity.

The flow regime of Lake Ozette tributaries can be defined as rain-dominated and flashy, with low and high flows commonly being separated by three orders of magnitude. While high discharge, turbidity, and SSC values last only for several hours to days for each event, over a dozen events can occur each year creating cumulatively poor conditions for salmonids.

LIMITING FACTORS AFFECTING LAKE OZETTE SOCKEYE

Limiting factors affecting Lake Ozette sockeye are identified by geographic area: estuary and nearshore environment; Ozette River; Lake Ozette; Lake Ozette tributaries; off-shore marine environment. Within each geographical area, limiting factors are further described by sockeye salmon life history stage.

ESTUARY AND NEARSHORE ENVIRONMENT

Physical changes to the nearshore environment have not been documented. The region is remote and relatively pristine. The effect of climatic forces on ocean temperatures and water current patterns can result in seasonal variations in nearshore productivity, which can alter the nutrients available to juvenile and adult sockeye. However, the effects of changes in the early marine juvenile rearing conditions and late-stage marine life history of Lake Ozette sockeye are unknown. Available marine survival estimates for Lake Ozette sockeye are relatively high compared to survival estimates for other Northwest sockeye salmon populations. Changes in the tidal prism and estuarine habitat conditions appear to have occurred during the last 50 years, but the cause is poorly understood, as are the potential effects of the apparent changes on Lake Ozette sockeye salmon.

Predation on sockeye salmon in the Ozette River estuary and nearshore environment is not well documented. It is suspected that juvenile sockeye are preyed upon by avian, fish, and marine mammal predators during their migration through the estuary and nearshore, but the degree to which this occurs remains unknown. A substantial proportion (33%) of adult sockeye entering the Ozette River from the nearshore environment have scars associated with predation events, with 77% of these scarred fish having old scars and 52% with new scars. Of the identifiable scars on sockeye captured in the lower river, 25% were from wounds inflicted by California and Steller sea lions, while 60% were inflicted by harbor seals. Direct visual observations of predation by pinnipeds have been made, but are limited in quantity and quality. The current number of pinnipeds interacting with Lake Ozette sockeye in the estuary and nearshore environment has increased significantly in the last 50 years, consistent with upward population trends for these animals observed across the Washington coastal and Puget Sound regions. The abandonment of the Ozette Village (one of five Makah villages) near the mouth of the Ozette River over the last 100 years has decreased traditional native hunting of pinnipeds in the nearshore area, Ozette River and Lake Ozette, and has likely increased the local number of these sockeye predators.

Healthy populations of prey species (e.g., salmon) often overwhelm predators (e.g., pinnipeds) by migrating in mass past interaction points, reducing the total number and percentage of predator-prey interactions. Decreases in the number of adult sockeye returning and juveniles emigrating from Lake Ozette in the past are thought to have increased the percentage of the annual juvenile and adult populations preyed upon.

Currently there is no directed sockeye harvest by humans occurring in the nearshore marine environment or the Ozette River estuary. Commercial tribal sockeye harvest was discontinued in 1977. A tribal ceremonial and subsistence fishery took place in the river from 1978 to 1982, with no directed sockeye harvest since. Past over-exploitation in fisheries has been described as a factor for the decline of Ozette sockeye, but fisheries harvest is not currently limiting sockeye salmon viability.

OZETTE RIVER

Compared to other mainstem rivers of the region, the Ozette River retains much of its natural integrity, despite numerous anthropogenic modifications. Instream habitat conditions have been degraded by repeated LWD removal operations (1890s to 1980s) and patchy riparian forest removal, resulting in reduced LWD size, frequency, and functionality. However, a mostly intact riparian corridor along the Ozette River ensures a supply of future LWD. Degraded LWD and riparian conditions have altered migration and rearing conditions for juvenile and adult sockeye, specifically, pool depth and volume, cover availability, and refugia from predators.

Wood in the Ozette River plays an important role in channel roughness, creating a backwater effect that increases floodplain connectivity. In addition, LWD in at least the upper 3,000 feet of the Ozette River exerts a significant influence on lake level regimes, as well as a positive feedback on river discharge. Herrera (2005) modeled various wood loading scenarios in the upper Ozette River and determined that under historical wood loading conditions, the mean lake level during the beach sockeye spawning period was 1.5 to 3.3 feet higher than current conditions. More recently (1979 through 2003), sedimentation at the lake outlet from Coal Creek has further altered lake and river levels, slightly raising summer lake levels but reducing (blocking) low stream discharges for a given lake stage.

The impact of high water temperatures in the Ozette River on migrating Lake Ozette sockeye depends upon specific temperatures and exposure times of both individuals and the entire run. For return years 2002 to 2004, 16.3%, 21.3%, and 55.9%, respectively, of the adult sockeye runs migrating in the Ozette River were exposed to daily average temperatures greater than 18°C. The average duration of migration from the estuary to lake is approximately 65 hours (ranging from 17-154 hours). Direct en-route mortality due to exposure to water temperatures greater than 18°C during river migration has not been investigated for Lake Ozette sockeye salmon. Studies from other areas (e.g., the Fraser River) indicate that exposure to temperatures at or above 18°C could make the sockeye more susceptible to disease and infection (especially considering their extensive [up to 6-month] lake holding period), resulting in elevated pre-spawning mortality levels and/or decreased spawning success

Sources of turbidity and high suspended sediment concentrations (SSC) in the Ozette River are limited to inputs from Coal Creek and a few small tributaries. Modeled impacts of the high SSC recorded in the Ozette River on sockeye adults range from moderate physiological stress to major indications of physiological stress for 6% (May), 4.8%

(June), 1% (July), and much less than 1% (August) of the adult population, respectively. Cumulatively, approximately 12% of the migrating sockeye salmon population on average would be exposed to SSC that would be expected to result in moderate physiological stress.

Juvenile sockeye smolts are preyed upon by a host of predators in the Ozette River, including river otters, harbor seals, northern pikeminnow, cutthroat trout, birds, and terrestrial mammals. While no detailed studies have exclusively focused upon smolt predation during emigration, smolt trap data indicate that northern pikeminnow are significant predators of sockeye smolts in the Ozette River. Adult sockeye are preyed upon mainly by seals and river otters in the Ozette River, where both species have been observed to frequently transit the entire length of the river. Research has shown that the incidence of scarring on adult sockeye increased by 11% along the length of Ozette River, with a significant portion of upstream-bound fish tagged in the estuary being lost (unrecovered) in transit. Predator scarring rates on sockeye in the Ozette River are among the highest rates observed in the Pacific Northwest. Predator abundance and predation rates in the Ozette River are hypothesized to have been altered by the removal of LWD, which in turn resulted in less availability of refugia for sockeye and easier transit for seals; changes in discharge regime; increases in aquatic mammal abundance; abandonment of the Ozette Village and traditional hunting; decreases in sockeye abundance (resulting in less predator swamping); and fisheries management practices (regulations, monitoring), which have synergistically interacted to unbalance predator-prey interactions, causing an increase in the ratio of predators relative to numbers of remaining Lake Ozette sockeye salmon.

LAKE OZETTE

Spawning habitat availability around the perimeter of Lake Ozette is largely controlled by lake level regime, which is influenced by the hydraulic (backwater) conditions of the Ozette River outlet, in addition to the hydrologic conditions of tributary inflow. Under historical wood loading conditions in the Ozette River, the mean lake level during the beach sockeye spawning period was 1.5 to 3.3 feet higher than current conditions. It is hypothesized that reduced mean lake levels have reduced the available area of sockeye beach spawning habitat and increased the ability of vegetation to colonize the lake shorelines in spring and summer months. Tributary inflow hydrology and outlet hydraulics together control how rapidly lake levels rise and fall and how they are sustained at preferred spawning levels, thus influencing the probability of redds (eggs) becoming desiccated and dewatered (e.g., three percent of the redd surface area on Olsen's Beach was estimated [based on measurements or redds and lake level] to be dewatered during the sockeye egg incubation period in return year 2000). Known alterations to lake outlet hydraulics and known land use changes in tributary watersheds, with hypothesized hydrologic impacts, have altered lake level regimes beyond levels attributable to natural climatic variability to an unquantified degree.

The quantity and quality of beach spawning gravels in Lake Ozette have declined significantly from their historical conditions to present. Reduced spawning gravel quantity and quality are ***key*** limiting factors affecting the success of beach spawning sockeye in Lake Ozette. The degree to which habitat quantity and quality has been reduced has not been quantified for the entire lake shoreline. Habitat quality reduction varies by site. For example, the entire Umbrella Beach spawning area historically used for sockeye spawning has been covered by several acres of fine sediment originating from Umbrella Creek and no longer provides suitable habitat. Other potential spawning areas have been reduced by vegetation colonization. The degree of colonization varies from small scale increases in vegetation, to entire beach segments colonized by shrubs and grasses (adjacent to areas currently used by spawning sockeye).

Measured levels of fine sediment collected in spawning gravels on Olsen's and Allen's beaches average 25% fines (particles less than < 0.85mm; n=56; gravimetric method), but with high spatial variability. Egg basket studies indicate that the total green egg-to-emergence survival rate was extremely low (averaging less than 1%; ranging from 0 to 45%). Over 21 day eyed-egg survival trials, median survival in cleaned gravel (8%) was higher than in uncleaned gravel (2%). Concurrent hatchery incubated eggs in cleaned and un-cleaned gravel had survivals of 99% and 61%, respectively. Reduced sockeye egg survival measured in uncleaned Olsen's Beach gravel under optimal incubation conditions at the hatchery and devoid of other confounding factors present in the lake suggest that fine sediment plays a significant role in egg mortality. However, these data also strongly suggest that other factors also contribute to reduced survival (e.g. encroachment by vegetation, deleterious changes in upwelling characteristics, and deleterious changes in inter-gravel flow).

Delivery of fine sediment to the lake from tributaries has increased three-fold during the last 50 to 100 years (Herrera 2006), largely due to increased sediment production from forest roads, clear-cutting, channel incision, and agricultural development. Historically utilized beaches, such as Umbrella Beach, have a clear link between sediment source, delivery, and the elimination of beach spawning habitat (5.7 acres of delta growth 1964-2003). However, it is not fully understood to what degree these increases have affected the remaining utilized beach spawning habitats located at Olsen's and Allen's beaches. Sediment delivery from local tributaries and shore slopes, combined with lateral lake shore transport from winds from the south-southwest, are the likely primary mechanisms for fine sediment delivery to sockeye spawning habitat at these extant spawning locations. In addition, the reduction in the abundance of the sockeye population in Lake Ozette during the last 30 years may have reduced the population's effectiveness in cleaning and maintaining spawning gravels that are free from fine sediment and vegetation through the act of mass spawning.

Furthermore, colonization and encroachment of native and non-native vegetation on the lake shoreline influences the habitat quality, sediment particle size distribution, and sediment trapping efficiency of Lake Ozette spawning beaches. There has been a substantial increase in shoreline vegetation (shrubs and grasses) during the last 50 years, hypothesized to be a result of long-term wood removal from Ozette River, lower lake levels during the growing season, reduced elk shoreline grazing, and vegetation colonization of newly delivered fine sediment from tributaries. In some locations, vegetation has completely blocked or smothered access to traditional spawning sites, while in other areas vegetation has decreased wave energy, promoting sediment deposition and reducing wind-driven currents needed to oxygenate eggs. The cumulative effects of vegetation colonization, sedimentation, and altered lake levels are hypothesized to have altered local hyporheic or groundwater flow paths and rates through spawning gravel, adversely affecting the quality of the incubation environment (i.e., egg oxygenation, waste removal).

In addition to degradation of habitat quality, the quantity of potential beach spawning habitat has also been reduced. While the number of beach spawning aggregations that have been extirpated is unknown, the strategy of spawning at creek mouths is no longer observed for Lake Ozette sockeye (e.g., Umbrella Creek and other tributaries). Colonization by native and non-native plants in spawning gravel decreased the extent of unvegetated (bare substrate) shoreline by an average of 56% from 1953 to 2003, directly reducing the quantity of spawning habitat available for sockeye. At Olsen's and Allen's beaches, the decrease in unvegetated shoreline area was higher than average, at 66 % and 67%, respectively.

Altered lake level regimes resulting from changes in outlet hydraulics and inflow hydrology have also reduced the amount of spawning gravel habitat inundated, and therefore available for sockeye salmon use, during the spawning and incubation period. The average reduction (1.5 to 3.3 feet) of lake levels during spawning and incubation period because of removal of wood at the Ozette River outlet has decreased the available spawning habitat area at Olsen's Beach by 11% to 33%. The cumulative effects of changes in lake level, increased vegetation colonization, and elevated sediment deposition levels have reduced the suitable spawning habitat (above 31.5 ft MSL) area by greater than 70% at Olsen's and Allen's beaches.

Predation on sockeye salmon occurs during all life history phases within the lake. Juvenile sockeye and smolts are preyed upon by a host of predators in Lake Ozette including northern pikeminnow, cutthroat trout, sculpin, other native and non-native fishes, and birds. In the limnetic (open water) zone of Lake Ozette, cutthroat trout have been documented to be the major predator of juvenile *O. nerka*, whereas northern pikeminnow are less significant predators because they feed less in the limnetic zone. However, northern pikeminnow, sculpin, cutthroat trout, juvenile steelhead trout, juvenile coho salmon, yellow perch, and largemouth bass may be significant predators where they interact with juvenile sockeye along lake margins and near tributary confluences.

Adult sockeye are preyed upon mainly by harbor seals and river otters in Lake Ozette. Harbor seals are most commonly observed in the lake during fall and winter months during adult spawning, but seals are also encountered during spring or early summer during sockeye migration. Seals were not observed in the lake until the late 1980s. The number of harbor seals that frequent Lake Ozette appears to be low (two to four animals), but spawning sockeye are extremely vulnerable to predation, and the limited number of beach spawners in the lake could be significantly negatively impacted by only a handful of seals. Beach carcass studies also indicate that river otters are a major predator of adult sockeye in the lake. However, there is the potential that river otters scavenge the remains of sockeye that were captured and killed by harbor seals, implicating the wrong animal.

Disease is believed to have a low impact on the survival and abundance of adult sockeye holding in Lake Ozette. There is no direct evidence of significant disease mortality of free swimming adult sockeye in the lake during the up to six-month holding period. However, little is known about this life stage of Lake Ozette sockeye, and fish losses to disease cannot be entirely discounted as a potential limiting factor. In some years, only a fraction of the adult fish enumerated at the weir have been accounted for during lake and tributary spawning ground surveys, suggesting the potential for significant mortality from disease, secondary infections due to lacerations, direct predation, or unknown factors.

Hatchery practices implemented through the Hatchery Genetic Management Plan include measures to minimize potential disease and genetic impacts to beach spawning aggregations. The Umbrella Creek Hatchery "stock" poses limited genetic risk from breeding with beach spawning sockeye, since Umbrella Creek sockeye are essentially the same genetically as Olsen's Beach sockeye. Mark and recapture data collected at Olsen's and Allen's beaches indicate that few, if any Umbrella Creek hatchery releases return to spawn on Lake Ozette beaches.

LAKE OZETTE TRIBUTARIES

Lack of long-term hydrologic data sets in the Ozette watershed preclude precise quantification of any potential changes to hydrology and flow regimes from land use and channel modifications. However, forest harvest data (showing that greater than 90% of the watershed has been logged once and 33% to 60% has consistently remained hydrologically immature), road density data (averaging 5.5 miles/mi^2) in the Lake Ozette basin, and loss of floodplain connectivity and water storage (loss of LWD), along with a thorough literature review of forest hydrological processes, strongly suggest that these anthropogenic perturbations may have resulted in alterations in common peak flows (0.5- to 2-year recurrence intervals) and baseflows (i.e., historically higher progressing toward chronically lower).

Natural or anthropogenically modified variability in streamflow can affect salmonid habitat availability via velocity and depth or gravel area covered by water. Low flows and delayed seasonal high flows can alter adult migration timing, influencing predation rates or overall fitness. Highly variable discharge during spawning can force fish to spawn high in the channel cross-section, increasing the probability of later redd desiccation, or it may force fish to spawn low in the channel, increasing the probability of redd scour.

Summer temperatures in most major tributaries regularly exceed the standard environmental temperatures preferred by salmon (10-12°C) and trout (15°C); however, there is very little overlap between natural-origin sockeye and stream temperatures exceeding 16°C. In contrast, low ph values during low and high discharges can inhibit successful spawning and incubation, as hypothesized for Crooked and Coal Creeks.

Past and recent turbidity measurements in Lake Ozette tributaries indicate that turbidity levels regularly exceed 100 NTU during storm events in most tributaries, with extremely high levels (exceeding 500 NTU) measured in Umbrella Creek and Big River. In Coal Creek, paired turbidity and SSC measurements indicate that SSC values can exceed 1,000 mg/L at turbidity values of 300 NTU. Peaks in turbidity and SSC closely follow the patterns of water discharge in each tributary, indicating that the abundant fine sediment is transport limited. Elevated turbidity and SSC levels can directly and indirectly affect fish survival through altered behavior, physiology, and habitat quantity and quality. While high discharge, turbidity, and SSC values are limited in duration (only lasting for several hours to days for each storm event), the high frequency of such events (over a dozen events each year) can create cumulatively poor conditions for salmonids. In all tributaries, on average the duration of turbidity and SSC exposure is greater during fall and winter (adult spawning and incubation) than spring (juvenile emigration from tributaries). Modeled impacts of SSC on sockeye adults and smolts during spring floods in Coal Creek range from moderate physiological stress to major physiological stress. Because of the significantly higher turbidity and SSC values in Big River and Umbrella Creek, it is likely that the impacts on sockeye behavior, physiology, and habitat are greater there.

Channel-floodplain-riparian connectivity plays an important role in sediment transport and storage dynamics, as well as in regulating hydraulic and hydrologic processes. Cumulatively, altered floodplain processes coupled with other changes in watershed processes, such as increased sediment and water production and delivery to the channel network, can result in increased fine sediment levels, decreased bed stability, and increased sediment delivery to the lake. Loss of large riparian conifer vegetation because of floodplain development or logging has resulted in a decrease in LWD in most tributaries. In the habitat segments of major Lake Ozette tributaries defined for research purposes, the number of LWD pieces per 100 meters of stream length rated good in 25% of the segments; LWD greater than 50cm in diameter per 100 meters of stream length rated good in 23%; but key pieces/BFW rated good in only one percent of segments. A high frequency of large-diameter pieces of LWD is highly correlated with reaches with undisturbed riparian zones. In Ozette stream channels and floodplains, “key piece LWD” is an important roughness component that dissipates energy, promotes channel stability, creates complex aquatic habitat, increases floodplain connectivity, stores spawning sediment, and filters fine sediment.

In many Lake Ozette tributaries, the quantity of suitable spawning habitat has been reduced as a result of LWD removal, reduced LWD recruitment, increased fine sediment inputs and abundance, channelization and bank armoring, gravel mining, and colonization of bar deposits by non-native vegetation. In some reaches of Big River and Umbrella Creek, spawning gravel beds have been completely converted to sand bed or cobble bed, respectively. However, current sockeye salmon run sizes in the tributaries (less than 5,000 adult sockeye) occupy a small fraction of available habitat and thus are not currently limited by habitat quantity.

Spawning habitat quality in Lake Ozette tributaries is affected by channel stability and, more specifically, by redd scour. Channel stability and scour is influenced by many factors, including peak streamflow, sediment inputs, sediment transport imbalances, bed and bank material, size and density of LWD, and channel-floodplain connectivity. It is hypothesized that the combined influence of increased common peak flood magnitude, increased sedimentation of spawning reaches, reduced wood loads, and/or channelization and floodplain disconnection have synergistically destabilized relative bed stability and reduced sockeye egg-to-fry survival. Numerous observations have been made of highly mobile stream beds in tributary spawning areas, but no direct monitoring of scour depth has been conducted. Identification of the effects of gravel movement and redd scour on Lake Ozette sockeye salmon survival and productivity remains a data gap.

Reduced spawning gravel quality and the accumulation of fine sediment in spawning gravels during egg incubation appear to be *key* limiting factors affecting the success of tributary spawning sockeye. High levels of fine sediment in spawning gravels can reduce or block water exchange, oxygen delivery, waste removal, and fry emergence. It is hypothesized that fine sediment production has increased in the Lake Ozette watershed following European-American settlement by a factor of three, due to changes in land use (vegetation clearing, logging, road building). While no pre-disturbance fine sediment data are available for Ozette tributaries, in nearby undisturbed drainage basins with similar geology, fine sediment levels rarely exceed 10%. Under current, post-disturbance conditions, Lake Ozette tributaries have some of the highest levels of fine sediment (18.7% volumetric) measured in spawning gravels on the north Olympic Peninsula. Salmonid egg-to-alevin survival has been shown to decrease drastically when fine sediment concentrations exceed 13% (volumetric method).

Predation on juvenile and adult sockeye in Lake Ozette tributaries is poorly documented. During the period that adult sockeye enter, migrate, and hold in lake tributaries, they are primarily susceptible to predation by river otters, harbor seals, terrestrial mammals and birds (bald eagles, osprey). During spawning and egg incubation, sockeye eggs are susceptible to predation by sculpin, cutthroat trout, river otters, and birds (merganser, belted kingfisher). No studies of sockeye egg predation in the tributaries have been conducted nor has it been suggested that significant levels of egg predation are occurring. Upon emergence from the spawning gravel, sockeye fry are vulnerable to predation in tributaries by sculpin (sp), cutthroat trout, juvenile steelhead trout, juvenile coho salmon, and northern pikeminnow. Predator abundance and predation efficiencies in Ozette tributaries have been altered by LWD removal, which influences availability of refugia for sockeye, and loss of substrate refugia due to fine sediment deposition and embeddedness.

Within Lake Ozette tributaries, competition effects are limited primarily to impacts that may occur during spawning. Emergent sockeye fry quickly migrate to the lake upon emergence from the gravel, and food resource competition is not likely. Both intraspecific and interspecific competition exists in Lake Ozette tributaries: sockeye competing with one another for spawning habitat, sockeye competing and/or spawning with kokanee for spawning habitat, and sockeye competition with coho salmon for spawning habitat. The degree and type of competition thought to occur in tributaries varies by stream system, species population abundance, and habitat quality and availability. Within certain reaches with modest numbers of sockeye (Umbrella Creek), competition can be intense and redd superimposition can play a significant role in egg-to-fry survival. Spawning competition with coho salmon also occurs, since both species spawn at the same time and in similar habitat, but coho populations will need to increase before their competition with sockeye for spawning sites becomes a significant factor. Competition and interaction with kokanee is thought to be minimal in Umbrella Creek, since few kokanee spawn in this stream system. Interactions between the two *O. nerka* races are more common in other streams (Crooked Creek) where sockeye numbers are low but kokanee numbers are moderate. Tributary spawning ground surveys during the last 10 years have provided no evidence of pre-spawning disease-induced mortality in the tributaries.

OFF SHORE MARINE ENVIRONMENT

Limited marine survival data indicate that *total* marine survival rates appear good, averaging 15 to 27%. Data for other Pacific Northwest sockeye salmon populations indicates that average marine survival for large sockeye smolts (>115mm) in the southern range of the ocean where Lake Ozette likely rear (latitude <55°N) averages 17.1%. While marine survival is a critical component in determining the ultimate abundance of Lake Ozette sockeye, broad-scale, regional studies of decadal-scale productivity suggest that changes in marine survival have played a limited role in the decline of Lake Ozette sockeye.

Since the discontinued tribal sockeye fishery in late 1970s, there have been no known directed sockeye fisheries that substantially affect Lake Ozette sockeye in the marine environment. No past or recent marine harvest data for Lake Ozette sockeye exist. Marine area migration timing for Lake Ozette sockeye salmon was estimated for Southeast Alaska and West Coast Vancouver Island marine areas. Ozette sockeye migration timing was charted relative to the timing of fisheries in recent years to determine whether the fisheries could be intercepting Lake Ozette sockeye. Alaskan fisheries appear to occur too late in the season to pose a threat of intercepting Ozette sockeye. West Coast Vancouver Island sockeye fisheries have been virtually closed since 1996, and less than 10% of Ozette sockeye could be subject to harvest if/when these fisheries operate. A small (one to two gill net boat) test fishery in Canadian Area 20 (one day's travel north from the mouth of the Ozette River) that is conducted to assess Fraser River sockeye salmon run strength and timing overlaps in timing with approximately 25% of the Lake Ozette sockeye return. This test fishery could intercept some Lake Ozette sockeye (Pacific Salmon Commission staff estimated that one Lake Ozette adult was encountered two years ago). However, DNA analysis has shown that the vast majority of fish caught originate from Lake Washington and the Fraser River during the period when Lake Ozette sockeye might be present in the test fishery. The Pacific Fishery Management Council states that southern U.S. coastal sport, commercial, and tribal fisheries have no measurable impact on sockeye salmon.

ANALYSIS OF LIMITING FACTORS BY LIFE STAGE

This report presents a series of limiting factors hypotheses by life stage, supported by a narrative describing reasoning and evidence. Each limiting factor hypothesis was evaluated based on the following definition of a limiting factor: physical, biological, or chemical conditions (e.g., inadequate spawning habitat, insufficient prey resources, and deleterious suspended sediment concentration) experienced by sockeye at the spawning aggregation scale resulting in reductions in viable salmonid population (VSP) parameters (abundance, productivity, spatial structure, and diversity).

The Lake Ozette Sockeye Steering Committee's Technical Workgroup evaluated and rated each of the limiting factors hypotheses based upon the degree of impact on the population or sub-population during each life stage. The degree of impact of each limiting factor was categorized as one of the following: unknown, negligible, low, moderate, or high.

In addition, a narrative describing the rationale for determining a specific degree of impact and certainty of impact (low, medium, high, N/A) was characterized by the group for each limiting factor hypothesis. Sub-hypotheses were developed for some complex limiting factors, which include linkage between each limiting factor and the processes and/or threats that may influence the limiting factor. Most sub-hypotheses include a link to the sub-section of the report where detailed supporting evidence can be found. Key limiting factors are those with the greatest (highest) impacts on a population's ability to reach its desired status.

LIMITING FACTORS AFFECTING ALL POPULATION SEGMENTS

High Level of Impact
- Predation on juvenile sockeye in the Lake Ozette pelagic zone
- Marine survival

Moderate Level of Impact
- Predation during adult migration
- Predation during juvenile emigration
- Water quality during adult migration

Low Level of Impact
- Ozette River habitat during adult migration
- Ozette River habitat during juvenile emigration
- Research and monitoring during adult migration
- Research and monitoring during juvenile emigration

Unknown Level of Impact
- Disease: all life stages
- Estuary alterations: adult and juvenile stages
- Streamflow alterations: adult and juvenile stages
- Water quality during adult holding
- Predation during adult holding

LIMITING FACTORS AFFECTING BEACH SPAWNERS

High Level of Impact
- Predation during adult spawning
- Reduced suitable spawning substrate during incubation
- Fine sediment in gravel during incubation
- Vegetation encroachment during incubation

Moderate Level of Impact
- Fine sediment in gravel during fry emergence
- Seasonal lake level change during incubation and emergence

Low Level of Impact
- Predation during adult staging near beaches
- Redd superimposition during spawning/incubation

Unknown Level of Impact
- Predation during incubation and emergence
- Water quality during adult staging and spawning
- Low population size (habitat maintenance) during incubation

LIMITING FACTORS AFFECTING TRIBUTARY SPAWNERS

High Level of Impact
- Fine sediment in gravel during incubation
- Water quality during incubation

Moderate Level of Impact
- Predation during fry emergence and emigration

Low Level of Impact
- Predation during adult migration, spawning and incubation
- Pool habitat during adult migration and spawning
- Streamflow during adult migration, spawning, and fry emigration
- Water quality during adult migration, spawning, and fry emigration
- Research and monitoring during egg incubation

Unknown Level of Impact
- Streamflow during egg incubation

CONTENTS

FIGURES

TABLES

LIST OF ACRONYMS/ABBREVIATIONS USED

ATU	Accumulated Thermal Unit
BFD	Bankfull Depth
BFW	Bankfull Width
BIA	Bureau of Indian Affairs
BMP	Best Management Practice
BRT	Biological Review Team
BY	Brood Year
CART	Combined Acoustic Radio Tag
CCNWCB	Clallam County Noxious Weed Control Board
cfs	Cubic Feet per Second
cfs/Mi^2	Cubic Feet per Second per Square Mile
CMZ	Channel Migration Zone
CW	Channel Width
DBH	Diameter at Breast Height
DEM	Digital Elevation Model
DFO	Department of Fisheries and Oceans Canada
DHVSM	Distributed Hydrologic Vegetation Simulation Model
ESA	Endangered Species Act
ESU	Evolutionarily Significant Unit
FL	Fork Length
GLO	Government Land Office
HCP	Habitat Conservation Plan
HEC-RAS	Hydraulic Engineering Centers River Analysis System
HGMP	Hatchery and Genetic Management Plan
HOF	Hortonian Overland Flow
HORs	Hatchery Origin Recruits
IHN	Infectious Hematopoietic Necrosis
IMST	Independent Multidisciplinary Science Team
IPCC	Intergovernmental Panel on Climate Change
JRMP	Joint Resource Management Plan
LBT	Left Bank Tributary
LFA	Limiting Factors Analysis
LWD	Large Woody Debris
MDN	Marine Derived Nutrients
MFM	Makah Fisheries Management
MMPA	Marine Mammal Protection Act
MSL	Mean Sea Level
NCDC	National Climate Data Center
NGVD 1929	National Geodetic Vertical Datum of 1929
NMFS	National Marine Fisheries Service
NMML	National Marine Mammal Laboratory
NOAA	National Oceanic and Atmospheric Administration

NORs	Natural Origin Recruits
NPS	National Park Service
NWS	National Weather Service
ONF	Olympic National Forest
ONP	Olympic National Park
PFMC	Pacific Fishery Management Council
PNW	Pacific Northwest
POT	Peaks Over Threshold
PRISM	Parameter-elevation Regressions on Independent Slopes Model
PSC	Pacific Salmon Commission
RBT	Right Bank Tributary
QIN	Quinault Indian Nation
QNR	Quileute Natural Resources
RI	Recurrence Interval
RM	River Mile
RMIS	Regional Mark Information System
RMP	Resource Management Plan
RY	Return Year
SASSI	Salmon and Steelhead Stock Inventory
SCAS	Spatial Climate Analysis Service
SEAK	Southeast Alaska
SL	Standard Length
SSC	Suspended Sediment Concentration
SSHIAP	Salmon Steelhead Habitat Inventory and Assessment Project
TE	Trap efficiency
TFW	Timber, Fish, and Wildlife
TL	Total length
TRT	Technical Recovery Team
UJNR	United States and Japan Natural Resources
USBOR	United States Bureau of Reclamation
USCG	United States Coast Guard
USFS	United States Forest Service
USGS	United States Geological Survey
USFWS	United States Fish and Wildlife Service
VSP	Viable Salmonid Population
WAU	Watershed Administrative Unit
WSVI	West Coast Vancouver Island
WDF	Washington Department of Fisheries (now WDFW)
WDFW	Washington State Department of Fish and Wildlife
WDNR	Washington State Department of Natural Resources
WDOE	Washington State Department of Ecology
WFPB	Washington State Forest Practice Board
WRIA	Water Resource Inventory Area

ACKNOWLEDGEMENTS

The synthesis of past and present research in the Lake Ozette watershed and beyond would not be possible without the dedication of dozens of scientists and others who have been directly involved with Ozette sockeye on the ground and in the office over the last 30 years. The authors would like to thank past and present scientists and staff from the Makah Indian Tribe (John Blum, Gwen Bridge, Larry Cooke, Vince Cooke, Ned Currence, Denise Dailey, Joe Hinton, Mike Hunter, Steve Joner, Mark LaRiviere, William Lawrence, Steff Lucas, William Mahone Sr., Darrell Markishtum, Ringo McGimpsey, Thomas Parker, Caroline Peterschmidt, Dave Sones, Russell Svec, Lance Wilke), Washington Department of Fish and Wildlife (Chris Byrnes, Randy Cooper, Tim Rymer), NOAA Fisheries (Tim Tynan), Olympic National Park Service staff (Bill Baccus, Sam Brenkman, Pat Crain, Dan Larson, Sanny Lustig, John Meyer). If we have inadvertently missed anyone, we apologize and thank you, too, for your efforts.

The content of this report is the result of thousands of hours of discussions and efforts over the last 25 years, but especially the last seven, within the Lake Ozette Sockeye Steering Committee. The authors would like to thank all the members of the group for their dedication and tireless review of this document. Members of this group included:

- Clallam County (Joel Freudenthal, Cathy Lear)
- Governors Salmon Recovery Office (Phil Miller)
- Local Citizens and Landowners (Ed Bowen, Coleman Byrnes, Don Hamerquist, Randi Knox, Janeen Porter, Rob Snyder)
- Local Timber Companies
    - Consultants (Doug Martin, Jim Rochelle)
    - Green Crow (Tyler Crow, Harry Bell)
    - Merrill and Ring (Joe Murray, Wendy Sammarco, Norm Schaff)
    - Rayonier Timberlands (Ian MacIver)
- Makah Indian Tribe (Lyle Almond, Gwen Bridge, Jeremy Gillman, Joe Hinton, Micah McCarty, Caroline Peterschmidt, Russell Svec, Dave Sones)
- North Olympic Peninsula Lead Entity (Selinda Barkhuis)
- Northwest Indian Fisheries Commission (Debbie Preston)
- NOAA Fisheries (Rosemary Furfey, Tom Hooper, Matt Longenbaugh, Susan Pultz, Tim Tynan)
- NOAA- National Marine Mammal Laboratory (Pat Gearin)
- NOAA- Northwest Fisheries Science Center (George Pess)
- Olympic National Park (Sam Brenkman, Pat Crain, Dan Larson, John Meyer)
- Puget Sound Technical Recovery Team (Ken Currens, Bob Fuerstenberg, Bill Graeber, Kit Rawson, Mary Ruckelshaus)
- Quileute Tribe (Frank Geyer, Katie Krueger, Kris Northcutt)
- U.S. Environmental Protection Agency (Derek Poon)

- Washington State Department of Fish and Wildlife (Jeff Haymes, David Low, Ann Shaffer)
- Washington State Department of Natural Resources (Seth Barnes, Dave Christensen, Marcus Johns, Jim Springer)

Funding for document preparation came primarily from the Makah Indian Tribe, the Pacific Coast Salmon Recovery Fund, and NOAA Fisheries, but the distributed salaries of numerous agency employees and individuals were the foundation of the report.

Special thanks go to the cultural integrity maintained over the last 30 years by members of the Makah Indian Tribe, the Makah Tribal Council, and Makah Fisheries Department, who have refused to give up their special connection to the Ozette Watershed and these unique sockeye salmon.